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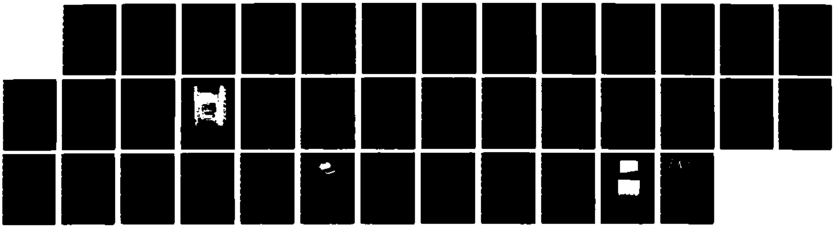

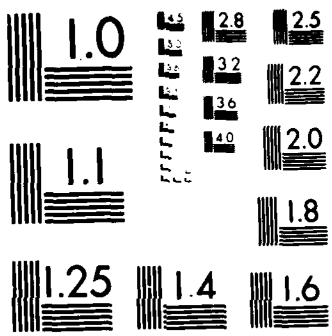

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Analog Fiber Optic Recirculating Delay Line

Final Technical Report for the period
September 1983 to March 1987

Prepared for

Naval Research Laboratories
Washington, D.C. 20375

Prepared by

T.R. Joseph, A. Jackson
TRW Electro-Optics Research Center
One Space Park
Redondo Beach, CA 90278

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ANALOG FIBER OPTIC RECIRCULATING DELAY LINE

Cdrl Sequence A002
for the
Analog Fiber Optic Recirculating Delay Line
Contract Number N00014-83-C-2322
Final Technical Report

Thomas R. Joseph
Assistant Manager
Electro-Optics Research Center

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The goal of this effort was to develop and demonstrate a fiber optic analog recirculating delay line. The wavelength was 1.3 μm, and the bandwidth was 1GHz. Transmitters, receivers and the interface amplifiers for two recirculating delay lines were fabricated and tested. Open loop data showed amplitude ripple of less than ±.15dB. Problems with vendors for the diode lasers precluded fully meeting all of the performance goals for the hardware.

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TABLE OF CONTENTS

Figures (Continued)

Tables

1.0 INTRODUCTION

1.1 PROGRAM GOALS

The goals of this program were to fabricate and deliver two optical analog repeaters for a recirculating fiber optic delay line with a 1 GHz bandwidth. The program was split into five tasks, Optical Receivers, Interface Amplifiers, Laser transmitters, Repeater Integration and Test, and Documentation and Delivery.

1.1.1 <u>Optical receivers</u>. This task consisted of the fabrication and test of two optical receivers incorporating 1.3 micron PIN photodiodes. These receivers are essentially identical to the receivers developed and delivered under NRL contract no. N00014-82-c-2285 with the addition of a fiber pigtail. The receivers performance goals were as follows:

Bandwidth	1.5Ghz(3dB)
Flatness	+/-.25dB(.01-1000MHz)
Transimpedance	>280 ohms
Fiber coupling loss	<.5dB

The receivers were to be fabricated as thin film hybrid circuits in 24 pin packages with a .5 meter graded-index fiber with a 50/125 micron core/cladding and a .2 NA.

1.1.2 <u>Interface Amplifiers</u>. This task involved the design fabrication and test of two prototype interface amplifier breadboards to provide sufficient gain to allow the receiver to drive the laser transmitter with a net loop gain of -1 dB. It was to include a manual gain control, and include a broadband monitor port to allow the circulating waveform to be sampled by a 50 ohm system. The amplifier also included a automatic gain control feature to allow the delay to be cleared by increasing the loop loss by 10 dB or more as required. The specific performance goals are:

Bandwidth	1.5 GHz (3dB)
Flatness	+/-.5dB (.01-1000MHz)
Impedance	50 ohms
VSWR	< 2:1

1.1.3. <u>Laser Transmitter</u>. This task is to design fabricate and test two prototypes of a single mode optical laser transmitter operating at 1.3 micron. The lasers were to be pigtailed with a .5 meter single mode fiber. The performance goals of the transmitter are:

Bandwidth	1.5GHz (3dB)
Flatness	+/- ,25dB
Quantum noise	< 140 dB/Hz
Second Harm. Suppression	-40dBc(500Mhz)
VSWR	< 2:1

1.1.4. <u>Repeater Integration and Test</u>. The transmitters receivers and interface amplifiers were to be integrated in two complete recirculating analog delay lines to test their performance. The parameters to be measured include open and closed loop frequency response, signal to noise ratio, and signal to distortion ratio, and stability.

1.1.5. <u>Documentation</u>. The two prototypes were to be delivered along with schematics, parts lists, measurement data, and a final report.

1.2. PROGRAM SUMMARY

Most of the program goals were achieved during the effort. The two receivers, the interface amplifiers and the transmitter driver circuits were all designed, fabricated, and tested.

However, the single mode lasers that were ordered for use in the transmitters were not received as specified and were not available in time to be used on this program. As a result the other subsystems were individually evaluated and the transmitters were tested using available lasers which did not have adequate bandwidth to meet all of the performance goals. The following sections describe the development of the three main subsystems and give the data that was obtained. This is followed by a discussion of the testing that was carried out on the complete system.

2.0 HARDWARE SUBSYSTEMS

2.1 Laser Transmitter Subsystem

The laser transmitter subsystem is functionally an electrical to optical signal converter. An electrical analog signal is input through a BNC type connector and a corresponding optical analog signal is output via a single mode optical fiber.

The transmitter subsystem aluminum enclosure is physically larger than the receiver subsystem enclosure, and it also has internal subdivision into two functional areas

The first contains an optical and thermal stabilization loop circuit board. This stabilization loop circuit board accepts a regulated dc voltage (+/-5V). Using the laser hybrids internal thermistor and PIN backfacet diode as sensors, the stabilization circuitry regulates both the thermal and optical operating parameters of the laser diode through the use of two negative feedback loops. These parameters may be manually adjusted via controls on the stabilization loop circuit board. Both temperature and light intensity may be adjusted independently. In addition, open loop switches permit a trouble-shooter the option of electrically isolating the laser from the control loops and allow its independent testing.

Figure 2-1 shows the placement of the components of the optical and thermal stabilization loop circuit board. Figure 2-2 is a schematic diagram of the thermal stabilization circuit and Table 2-1 gives a Parts list for the two stabilization loops.

The laser hybrid stripline fixture and the laser hybrid are e second functional transmitter subdivision. The stripline fixture board provides an impedance matching stripline from a BNC input connector to the RF drive signal input pin of the laser hybrid. Other socket pins on this circuit board provide for the proper routing of sensor outputs to the stabilization loops, control actuator return paths from those loops and the DC bias inputs for the laser hybrid.

Two prototype laser transmitters were fabricated for this effort. Several manufacturers devices were tested including, NEC, Lasertron, and General Optronics. Of these three, the ones closest to the specifications were made by Lasertron. This singlemode laser is furnished with a .5m length of fiber pigtailed internally to the laser. The center wavelength of the light was 1.3um. The lasers delivered to TRW were hand selected by the manufacturer to be as single frequency as possible.

Orders were placed for two lasers from Lasertron and one from Hitachi. There were delays in delivery of these devices such that the first delivery of a single laser from Lasertron was 12 months after the promised delivery date, and neither vendor would indicate when they would complete their orders. The laser received from Lasertron was found to have a narrower bandwidth than expected. It exhibited a dip in its response at between 700 d 900 Mhz depending upon the grounding of one of its pins. Based on this observation we opened the package and added several grounding straps using gold ribbon to improve the grounding internal to the package. A photograph of the inside of the laser after this modification is seen in Figure 2-3. The three gold ribbons are clearly visible. Figure 2-4 shows the frequency response of the transmitter with this laser before modification. The dip in the response at 900 MHz is clearly evident. Figure 2-5 shows the extremely flat response achieved after the addition of the grounds. This transmitter met the program goals in performance and the changes made were communicated with Lasertron, but they never were able to deliver the second laser or replace the laser that we modified which died soon after this data was taken. Thus no usable lasers were available during the time there was program funding to continue the transmitter development. To allow evaluation of the transmitter driver circuits and the integration and testing of the interface amplifiers and the receivers laboratory lasers were placed in the circuits that were adequate but did not meet the bandwidth goal.

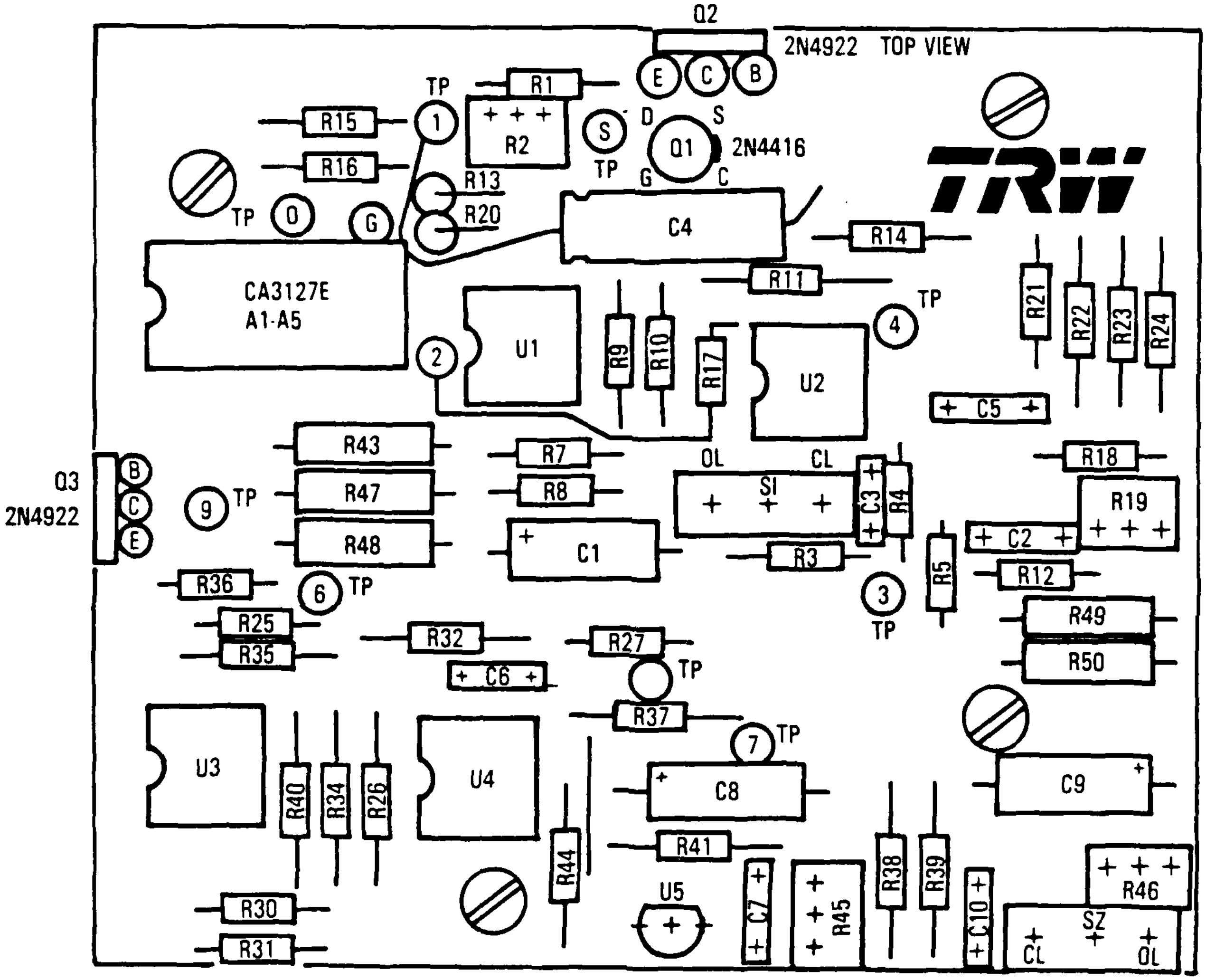

Figure 2-1. Component Placement Diagram for Laser Transmitter Optical and Thermal Stabilization Circuit Board.

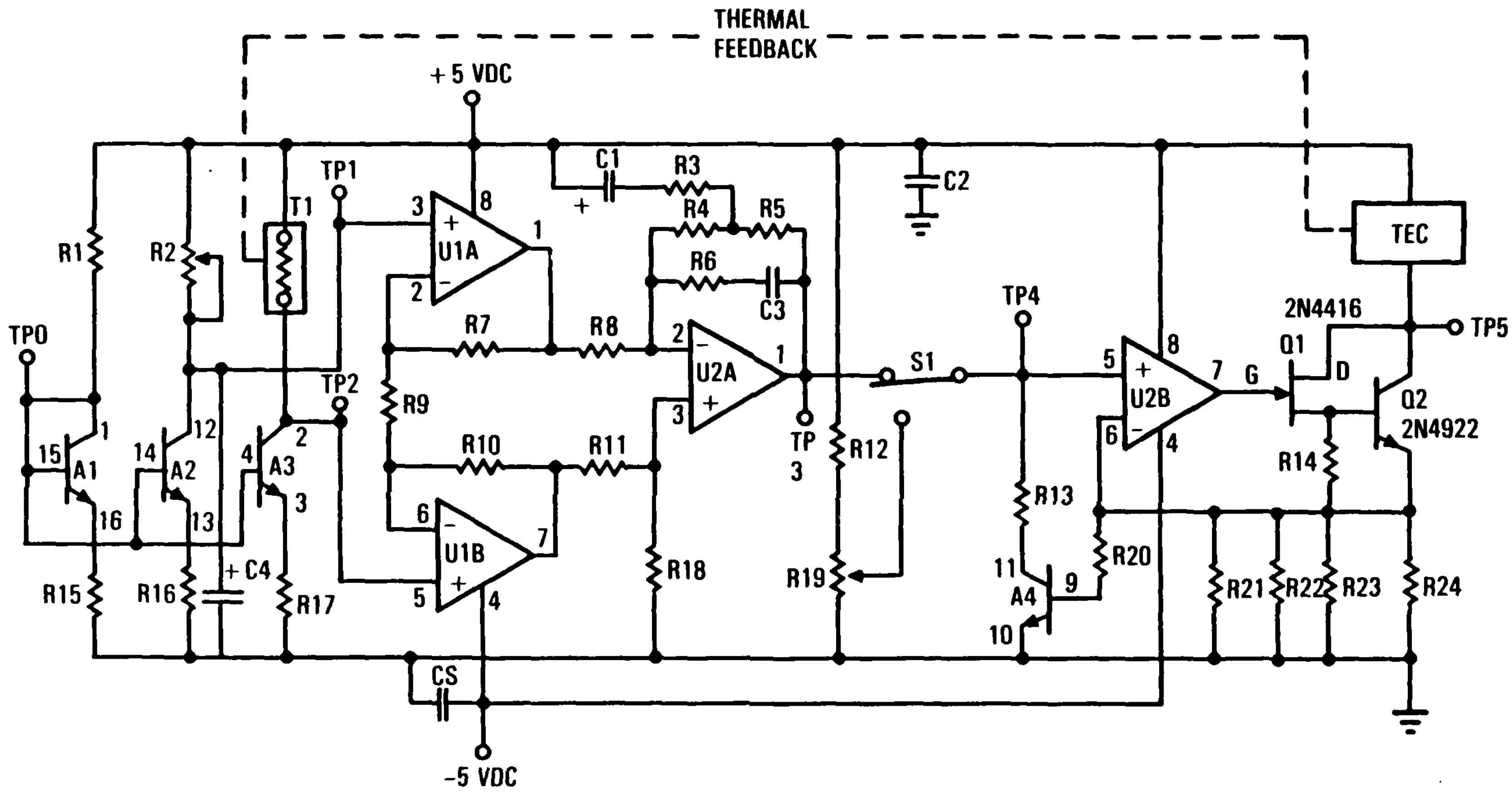

Figure 2-2. Schematic Diagram of the Thermal feedback circuit.

Table 2-1. Parts List for Laser Transmitter Subsystem.
(Includes Optical/Thermal Stabilization Circuit)

	(Omega)	Watt	
R1	27.4K	1/4	MF
R2,R46	20K	10 Turn Potentiometer	
R3	2K	1/4	Carbon
R4,5,7,10	15K	1/4	MF
R6	3K	1/4	Carbon
R8,11	10.5K	1/4	MF
R9	3.3K	1/4	MF
R12	110K	1/4	Carbon
R13,38,39	510	1/4	Carbon
R14	200K	1/4	MF
R15,16,17	2K	1/4	MF
R18	30.1K	1/4	MF
R19	2K	10 Turn Potentiometer	
R20	10	1/4	Cargon
R21,22,23,24	3.9	1/4	Carbon
R25	1K	1/4	MF
R26,40,44	49K	1/4	MF
R27	500K	1/4	MF
R29*	27	1/8	Carbon
R30,35	54.9K	1/4	MF
R31,36	21K	1/4	MF
R32	4.7K	1/4	MF
R34	10.2	1/4	MF
R37	4.7K	1/4	Carbon
R41	120	1/4	MF
R43	10	1/2	Carbon

Table 2-1

PARTS LIST FOR LASER TRANSMITTER SUBSYSTEM (CONTINUED)

	(Omega)		
R45	5K	10 Turn Potentiometer	
R47,48	16	1/2w	Carbon
R49,50	20	1/2w	Carbon
C1	4.7 µf	@35vdc	
C2,3,5,6,7,10	.1 µf	@100vdc	CK06
C4	4.7 µf	@ 25vdc	
C8,9	2.2 µf	@ 25vdc	
C11*	.1 µf	NPO Type Chip Capacitor	
U1,2,3,4	OP220	Dual Operational Amplifiers or CA081 Dual Bi-FET OP AMPS	
U5	LM317LZ	Adj. 3 Terminal Reg. I.C.	
A1,2,3,4,5	CA3127E	Monolithic NPN Transistor Array	
Q1	2N4416	FET N Channel Transistor (TO-18)	
Q2,3	2N4922	NPN BiPolar Tab Trans (TO-220)	
S1,2	SPDT	Subminiature Switch	
LD1*		Laser Diode	
PDI*		PIN Reference Photodiode	
LI*	15 µh	Torroidal Ferrite Inductor	
TI*		Fenwal Thermistor	
TEC*		Melcor Thermo Electric Cooler	

(* Devices Located Inside QLM 1300 SM Lasertron Package or Laser Matching Stripline Fixture)

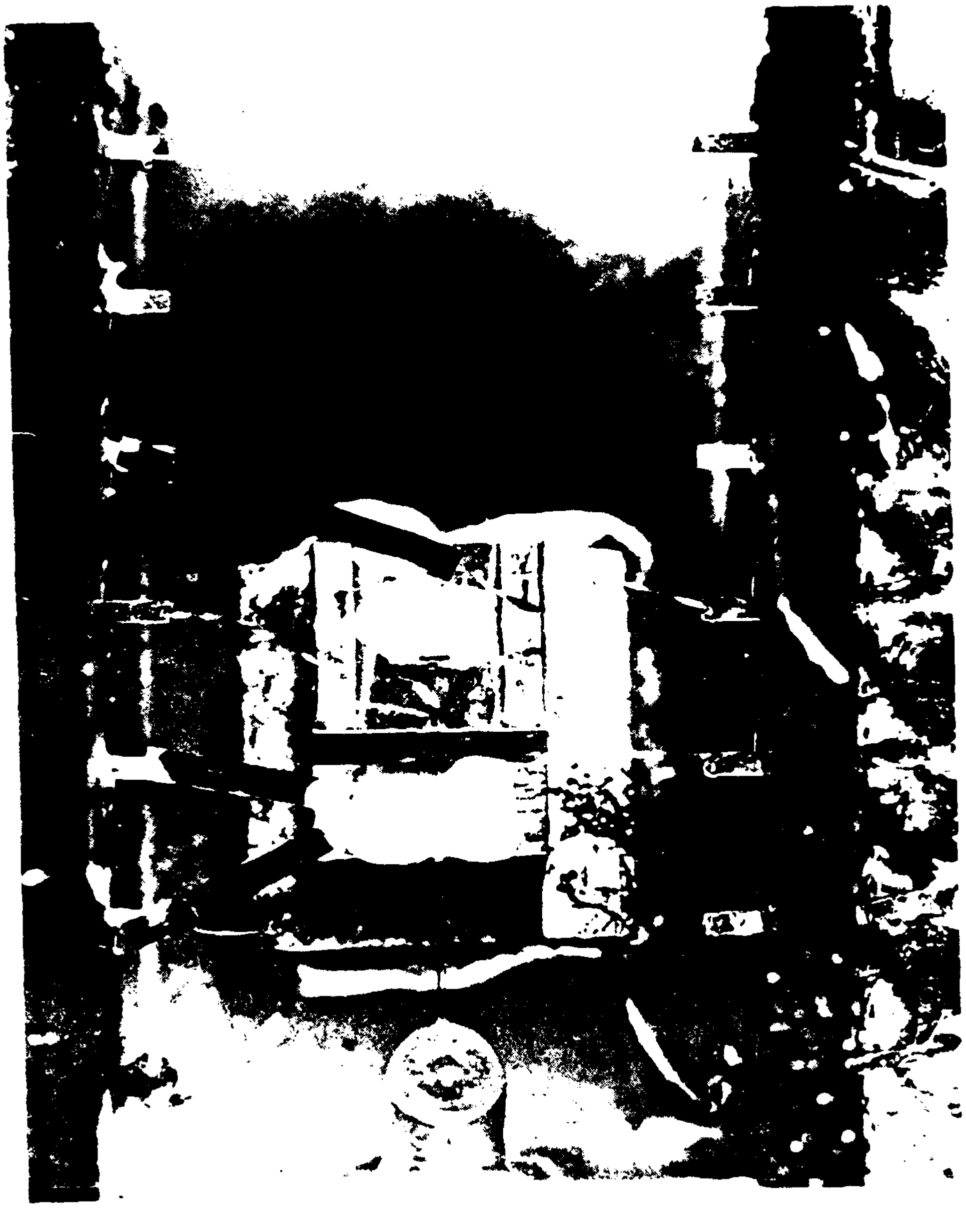

Figure 2-3. Photograph of Lasertron Laser After Modification.

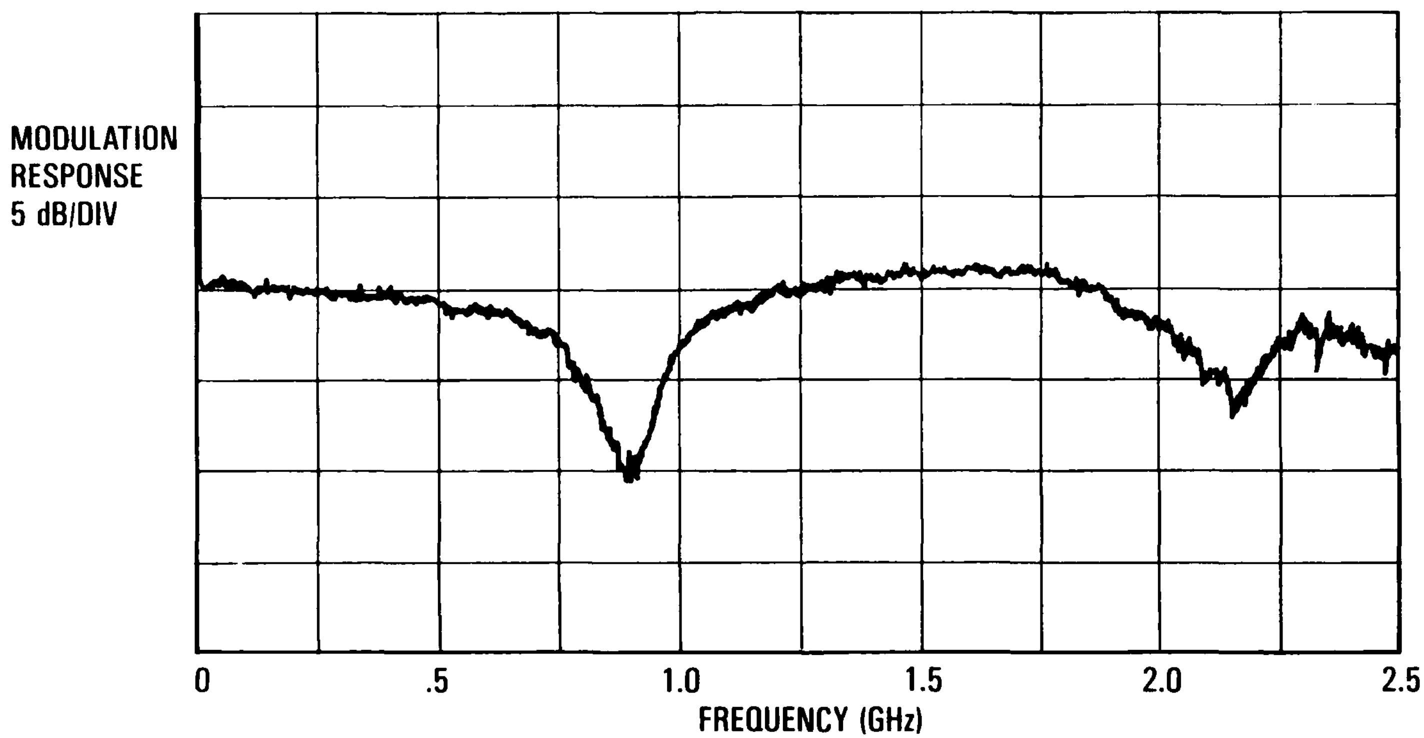

Figure 2-4. Frequency Response of Transmitter Subsystem Before Laser Modification.

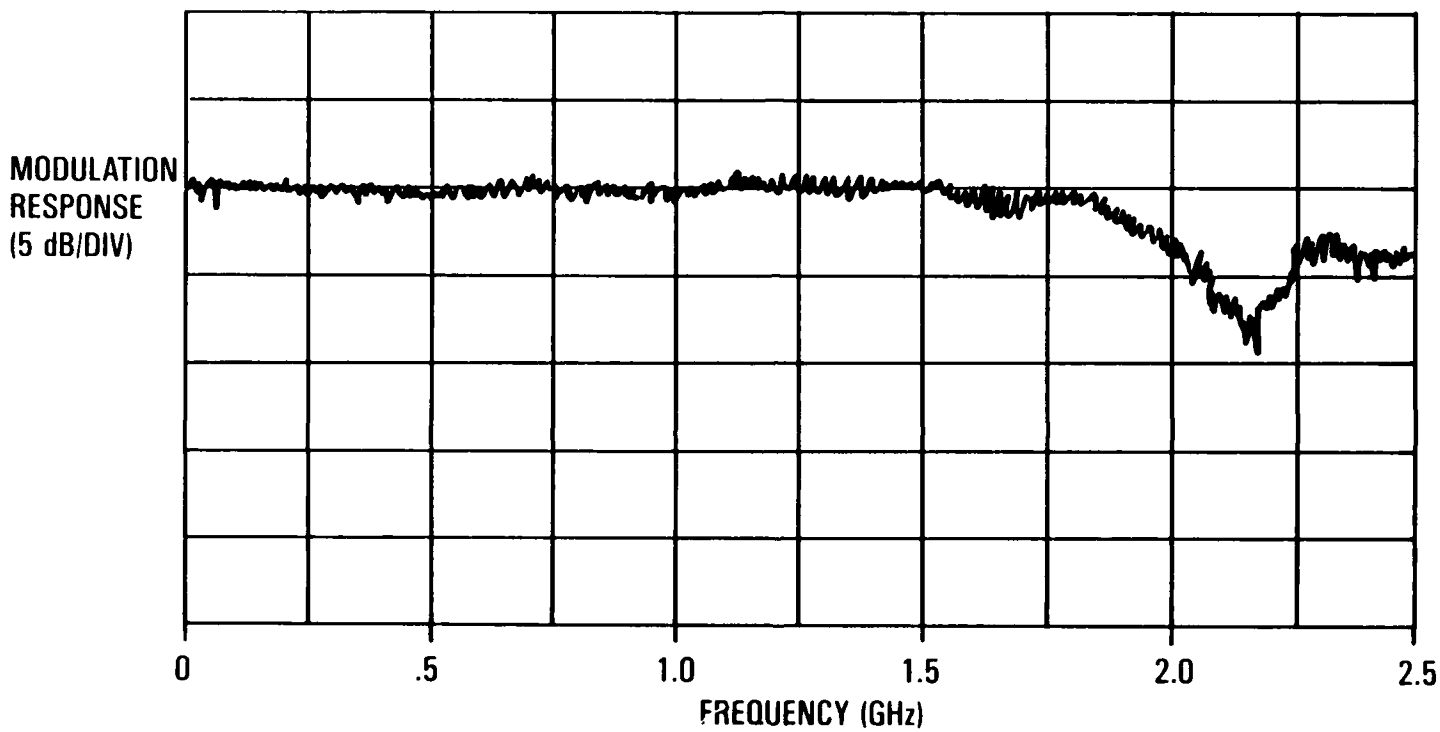

Figure 2-5. Frequency Response of Transmitter Subsystem After Laser Modification.

2.2 INTERFACE AMPLIFIER SUBSYSTEM

The interface amplifier subsystem is subdivided (both funconally and physically) in two portions. Functional subdivisions are, the equalizing amplifier circuit and the auxiliary amplifier circuit. These subdivisions have been placed within physically separate aluminum enclosures. There are a total of four analog electrical signal ports in the equalizing amplifier(and switch) circuit, signal insertion and extraction ports and dedicated signal output port. Fourteen dB of amplification is provided by this circuit to satisfy the current drive requirements of the adjacent laser transmitter subsystem.

2.2.1 Implementation of the Gain Equalizer

The gain equalizer was constructed of discrete components and hybrids soldered onto a printed circuit board. This circuit was placed into a COMPAC style case for RFI and EMI isolation as well as a structural support and for physical protection. A smaller version could be constructed in much the same manner using surface mount components and resistive networks on a smaller printed thick film circuit platform. This could be made to fit quite easily in a small case approximately one fourth the volume of the present amplifier. Indeed, there is a valid possibility that the equalizing amplifier would translate well into a hybrid circuit with the equalization adjustment located physically outside of the hybrid. The total of these outside adjustments could easily be four variable capacitors and one variable resistor.

Figure 2-6 is a schematic diagram of the equalization amplifier. Figure 2-7 shows the placement of the component parts on the circuit board. Table 2-2 gives the parts list for the equalizing amplifier.

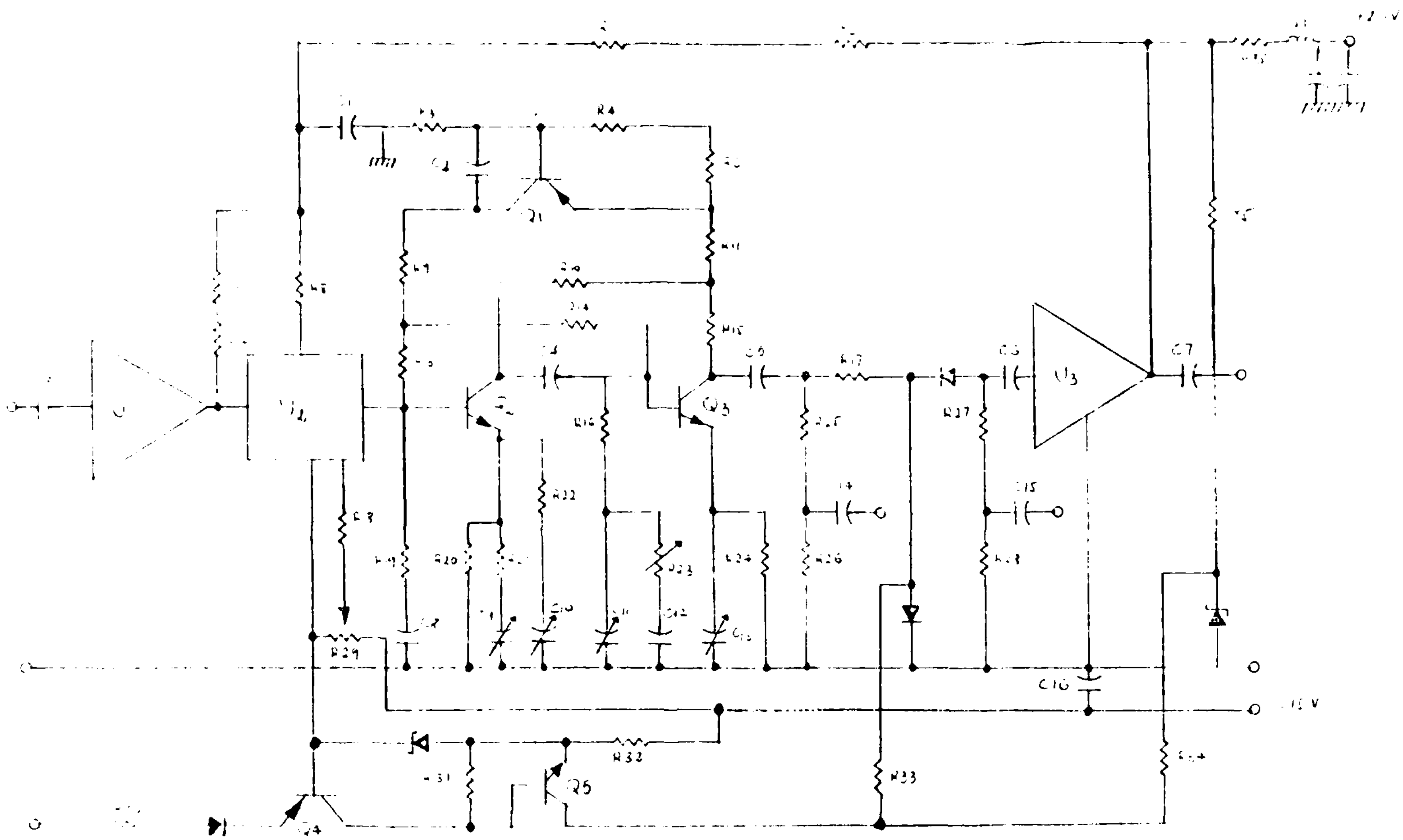

Figure 2-6. Schematic Diagram of the Equalization Amplifier.

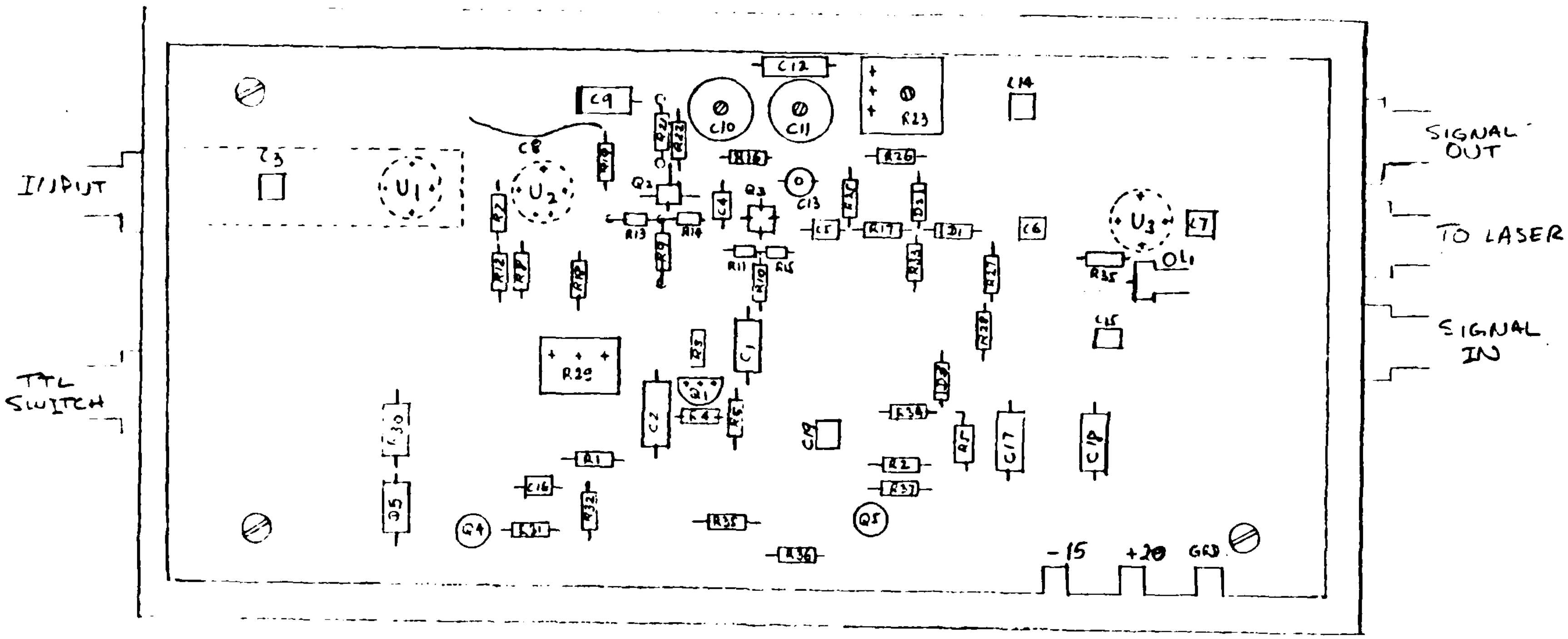

Figure 2-7. Parts Placement Diagram of the Equalization Amplifier.

TABLE 2-2 PARTS LIST INTERFACE AMPLIFIER SUBSYSTEM

	(Omega)		
R1,2,8,16,	20	1/8w	Carbon
R19,22	20	1/8	Carbon
R3	100K	1/8	Carbon
R5	1.5	1/4	Carbon
R6,7,12,25,27	100	1/8	Carbon
R9	15	1/8	Carbon
R10,11,15.18	160	1/8	Carbon
R13,14	120	1/8	Carbon
R17	33	1/8	Carbon
R20A,B,C	30	1/8	Carbon
R24A,B,C	30	1/8	Carbon
R21,35	75	1/8	Carbon
R23,27	1K	10 Turn Potentiometer	
R31,34	1K	1/8	Carbon
R26,28	82	1/8	Carbon
R29	5K	10 Turn Potentiometer	
R30	510	1/8	Carbon
R32	560	1/8	Carbon
R33	240	1/8	Carbon
R36	10	1/8	Carbon
C1,3,4,5,6	.1 µf	CK06	
C7,14,15,16	.1 µf	CK06	
C2	20pf		
C9,11,13	2-8pf variable capacitor		
C10	3 pf		
C12,17,18	.1 uf	CK06	
C8	1"22 AWG	Wire Variable Capacitor	
D1,2,5	IN914	Gen Purpose SIL Diode	
D3,4	IN5231	Sil Diode	
Q1	2N4403		
Q2,3	2NE645	NPN Microwave XSTR Ft. 10GHz	
Q4	2N2907S		
Q5	2N2222	NPN GP Sil BiPolar XSTR	
U1,3	TRW 1501	Wideband Amplifier	
U2	Avantek UTF 015 20 dB Var Atten		
L1	15 uH RF Choke Coil		

2.2.2 Tuning of the Equalizing Amplifier.

The equalizing amplifier is adjustable in the working frequency domain in five overlapping bands. This is more easily visualized by referring to the equalizing tuning curves shown in figure 2-8.

For each of the five bands there are individual adjustments. These are internal to the amplifier case. The adjustments are turned easily with the use of a non-conductive flat bladed tuning tool. It is recommended that a small metal screwdriver not be used for this adjustment. The use of metal tools disturbs the settings and a true adjustment is not possible.

It is advised that the adjuster begin by removing the case cover of the equalizing amplifier to gain access to the adjusting circuitry. The band to be equalized first should be the lowest in frequency. The procedure may initially seem complicated, however, with familiarity the procedure becomes quite intuitive. This lowest frequency band has a finite amplitude adjustment range. That is to say, even though the capacitor that is used to vary the equalization is of the continuously variable type, the range of adjustment will reciprocate in amplitude as the capacitor is varied. This effect is most easily observed on a network analyzer with a continuous sweep rate. This can be seen in Figure 2-8 where the three curves delineate the extremes and the middle of the adjustment ranges for each of the tuning bands. The network analyzer should be chosen with reference to the

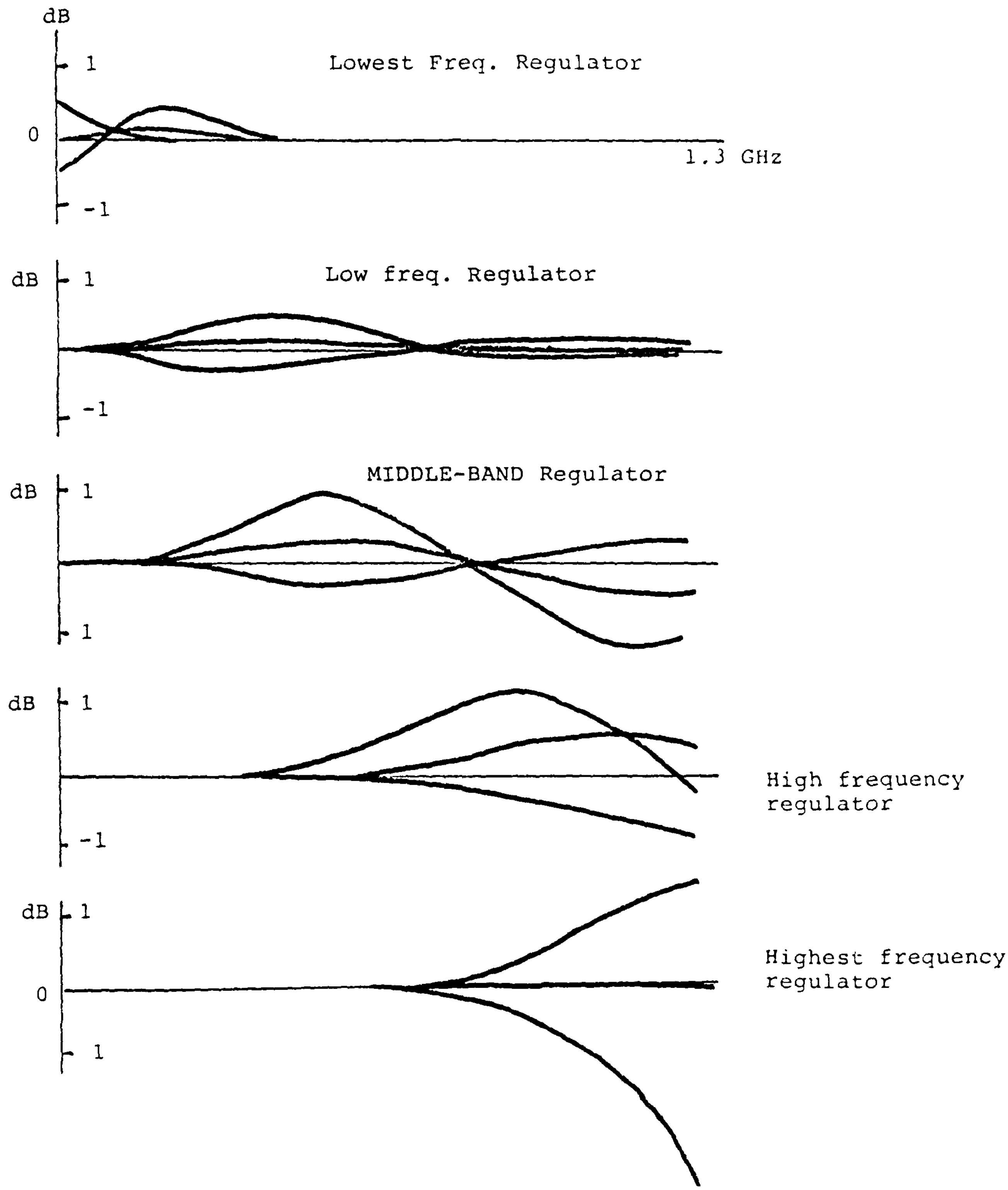

Figure 2-8. Tuning Curves for the Five Bands of the Equalization Amplifier.

bandwidth of interest of the equalizing amplifier to be adjusted. The analyzer should be set in the magnitude display mode with a scale setting that will allow resolution of .25dB adjustments. The lowest frequency band variable capacitor should be adjusted through a full revolution while watching the amplitude change through its full adjustment range. Try and mentally fix both the maximum and minimum variant limits of this adjustment. Once familiar with the full range of adjustment the test operator may fine tune the low band range to achieve as flat a response as possible within the frequency band. Now proceed to the next highest consecutive band adjustment and become familiar with its full range of adjustment. Recall at this point that when the band of adjustment is varied some effect will be observed in adjacent bands due to their overlapping nature. Also, a smaller effect will be seen in non-consecutive bands as adjustment is made due to inadequate isolation between the amplifier sections. As we proceed through the full range of the second lowest frequency band it is observed that the area equalized will be flattened in the frequency domain area below the most recently adjusted band. With the second band amplitude range determined proceed to adjust it to achieve maximum flatness within the band. The test operator will note at this point that the lowest bands may have lost some of their flatness. A word of advice--do not readjust lower bands until all bands have been consecutively set to their flattest response. A second pass through all adjustment bands can be made to furnish the desired response with a minimum of frustration. However, this must be systematic in approach with the second band fully compensated for flatness of response the operator may now proceed to the third band. The process of familiarization with the full amplitude adjustment is carried out in the same manner as the first two bands. The third band is then flattened in response. The procedure is repeated twice more. For the next two consecutive bands one at a time. Once all bands have been adjusted the operator may elect to repeat the procedure using the same sequential adjustments on a much finer scale.

2.3 OPTICAL RECEIVER SUBSYSTEM

The optical receiver subsystem is essentially an optical to electrical signal converter with integral electrical preamplification. Subsystem input is an optical signal introduced via a multimode (ITT 50/125) fiber optic cable. DC power is provided with nominal preregulation. Subsystem output is a (100kHz to 1.8GHz) wideband analog electrical signal which corresponds to the optical input signal.

Physically the receiver subsystem is enclosed in a COMPAC RFT style aluminum case that is subdivided into two internal compartments. The smaller of the two subdivisions contains the receiver hybrid bias regulator board.

This circuit accepts preregulated input voltages and provides three stable bias voltages with the high isolation required by the GHz bandwidth hybrid receiver. A schematic diagram of this circuit is shown in Figure 2-9, and Table 2-3 is the parts list. Figure 2-10 shows the parts placement in the receiver case. These three regulated bias voltages are then routed via commercial feedthrough filters to the adjacent compartment.

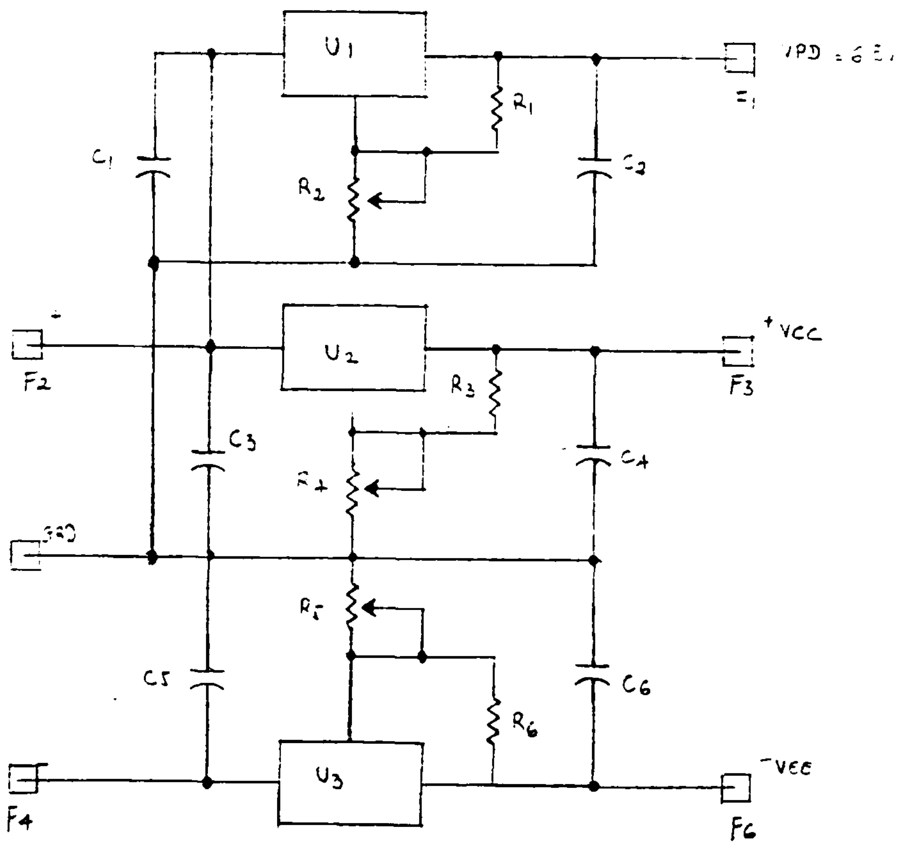

Figure 2-9. Schematic Diagram of the Receiver bias circuit.

TABLE 2-3 - PARTS LIST OPTICAL RECEIVER SUBSYSTEM

	(omega)		
Rl,3,6	120	1/2w	Carbon
R2,4,5	5K	10 Turn Potentiometer	
Cl,3	.1 uf	@25v CK06	
C2,4,5	1 uf	@25v CK)K	
C6	2.2uf	@25v	
Fl-6		Errie Feedthrough Filters	
Ul,2	LM317LZ	Adjustable Three Terminal Regulator I.C. Pos V.	
U3	LM337LZ	Adjustable Three Terminal Regulator I.C. Neg. V.	

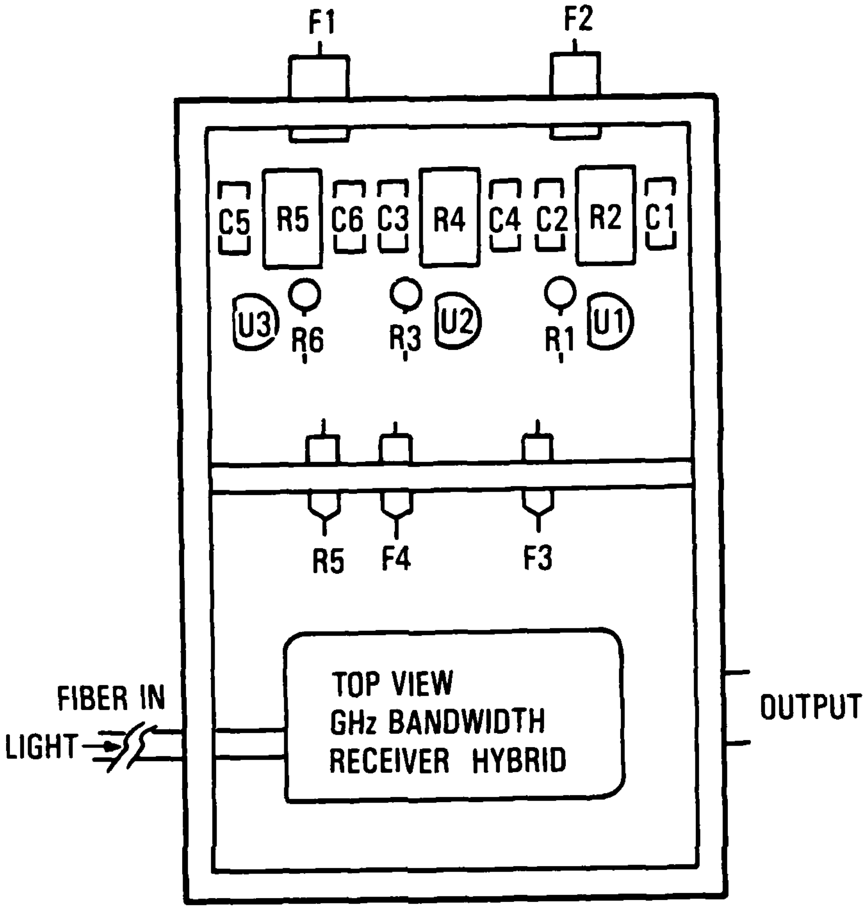

Figure 2-10. Receiver Parts Placement Diagram.

This second compartment provides EMI/RFI shielding for the hybrid receiver and structural support for the stripline fixture. Three bias voltages are routed to the hybrid socket bias pins and a high frequency stripline signal output path from the hybrid to an output BNC connector are provided by the stripline fixture board.

The hybrid circuit that forms the heart of the receiver was developed on the previous program and two copies were fabricated for this program. Figure 2-11 shows the pin out diagram for the hybrid and Figure 2-12 is a photograph of one of these hybrids and shows the frequency response.

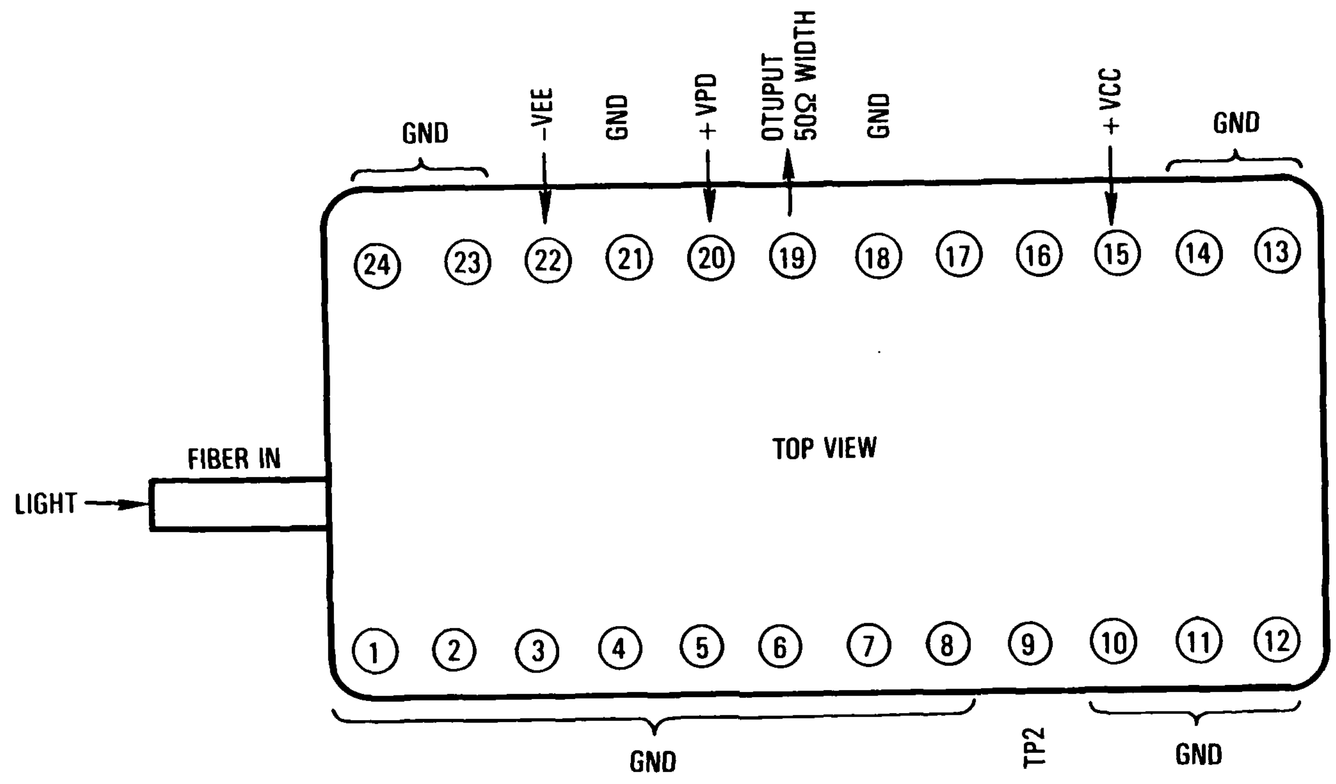

Figure 2-11. Pinout Diagram for the Receiver Hybrid.

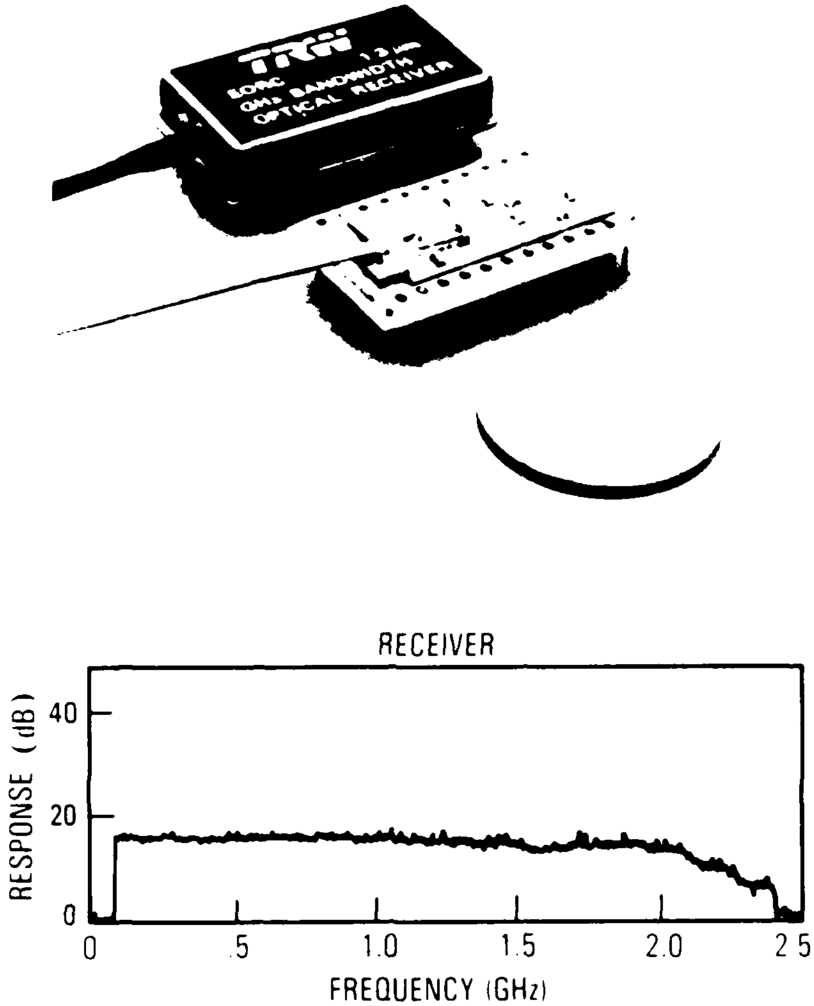

Figure 2-12. Photograph of the Receiver Hybrid and Frequency Response.

3.0. MEASURED RESULTS.

The subsystems of the recirculation delay line were fabricated and tested including the transmitters which were evaluated with lasers that were available at TRW. The following table gives the data on the performance that was achieved with this hardware.

Table 3-1. Measured Performance of the Recirculation Delay Line Hardware

PARAMETER	VALUE	GOAL	UNITS
RECEIVER SUBSYSTEM			
amplitude response flatness	+/-.25	+/-.25	dB
phase linearity in band	+/-2.5		deg
3dB bandwidth	1.2	1.5	GHz
transimpedance	280	>280	ohms
PIN responsivity	.63		A/W
receiver subsystem responsivity		168	V/W
input equiv. noise density	9		pa/(Hz)$^{1/2}$
3dB noise frequency	920		MHz
avg. noise power	1.13×10^{-13}		A^2
input equiv. noise resistance		146	>100ohms
VSWR	1.58:1	2:1	
INTERFACE AMPLIFIER SUBSYSTEM			
test fiber length	4		km
net loop gain	-.97	-1	dB

PARAMETER	VALUE	GOAL	UNITS
analog access port	1	1	
analog monitor port	1	1	
delay line clearing	binary	10dB loss	TTL level
bandwidth	1.5	1.5	GHz
response flatness	+/-.15	+/-.5	dB
gain	22		dB
VSWR in/out	1.4:1	2:1	
noise figure	5		dB
power supply	12V@12ma		
	20V@3ma		
number of equalization sections	5		
equalization range	+/-2		dB
equalization accuracy	+/-.2		dB

LASER TRANSMITTER.

bandwidth	700	1000	MHz
gain flatness	+/-.14	+/-.25	dB
wavelength	1.3	1.3	micron
modulation index	.05-.55	.25-.5	
temperature stabilization	+/-.09	+/-.2	degrees
optical transfer function	+/-0.6	+/-0.5	%

The repeaters were tested both open loop and closed loop using the laboratory lasers. Figure 3-1 shows a plot of the open loop flatness after the interface amplifier was adjusted to flatten the response. As is evident in the figure the frequency response is flat to within +/-0.15 dB over the band from 1 to 1250 MHz. The recirculating delay line was connected for closed loop tests and a short pulse was injected. This pulse was 3ns wide. Figure 3-2 shows the output of the monitor port on the interface amplifier as the pulse rings down. Figure 3-2a shows the ringdown of the pulse when the loop is set up for a -1 dB loss per circulation. Figure 3-2b shows the same result but with the loss set to -2.2 dB. There was sufficient gain in the interface amplifier to reduce the loss to 0 dB and as a result the loop would oscillate when the loss was close to that value.

4.0. SUMMARY AND CONCLUSION.

The hardware that was required to form two recirculation delay lines was fabricated and meets or exceeds most of the specifications. However there were unresolved problems in obtaining the wideband lasers that were needed to complete the two transmitters. As a result the testing was carried out using laboratory lasers rather than the ones which were ordered but were never received while there was funds to utilize them. The lack of funds at the end of the active portion of the program precluded successful completion of the effort. The concept of a wideband recirculation delay line has been demonstrated with this hardware and there is further effort that could be expended the refine this concept.

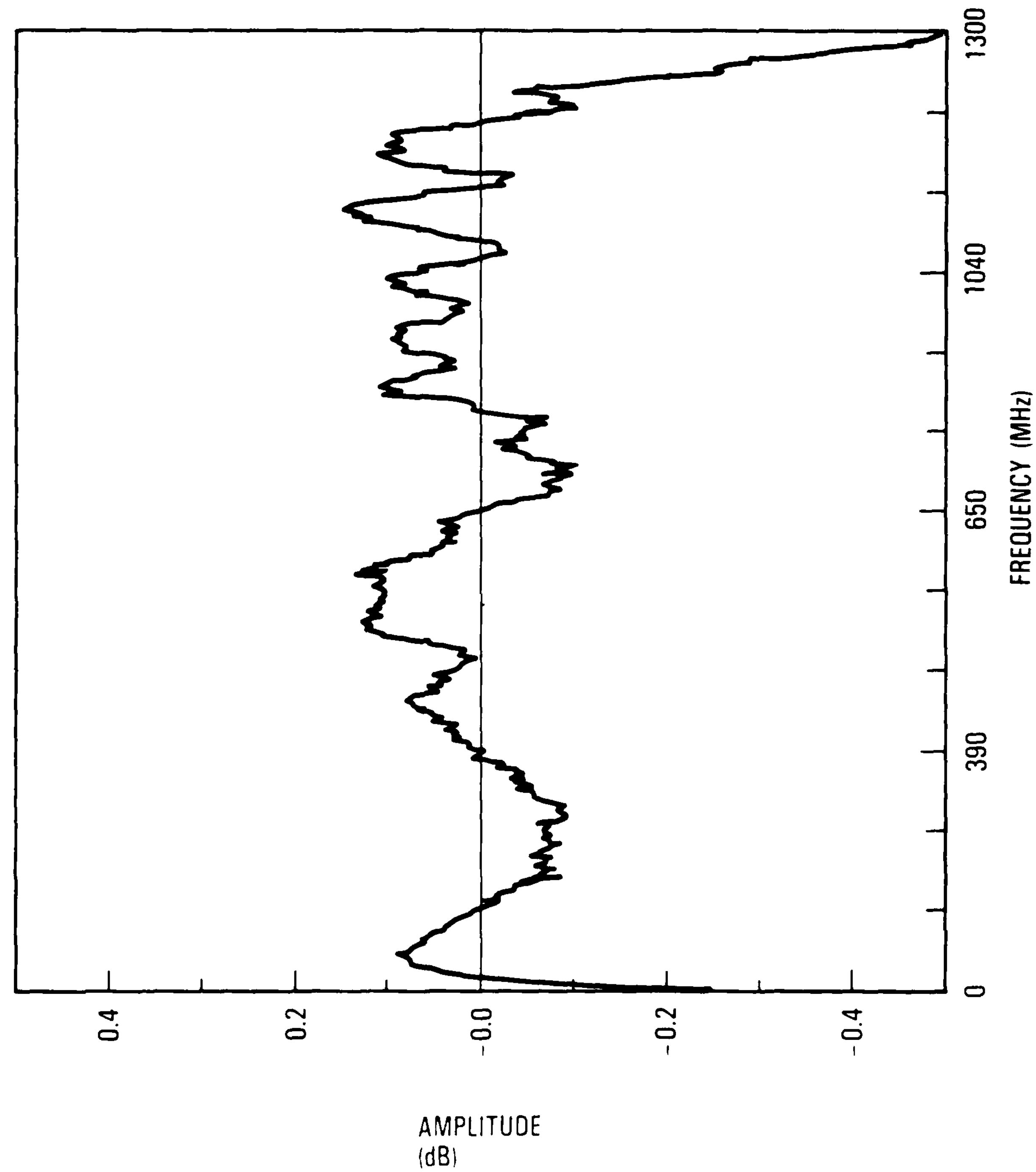

Figure 3-1. Frequency Response of the Recirculating Delay Line After Equalization.

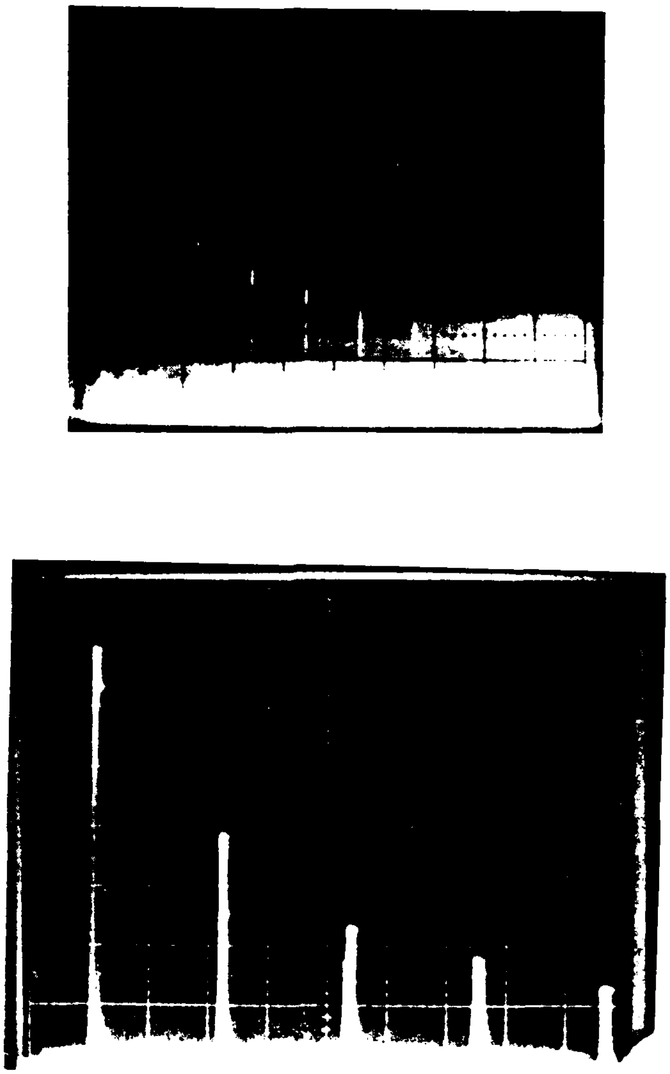

Figure 3-2. Ring Down of Pulses Injected into the Recirculating Delay Line.

END

4-87

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